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Genetic and Phenotypic (Co)Variances for Production Traits of Female Populations of Purebred and Composite Beef Cattle[1,2]

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ABSTRACT: Least squares means, genetic and phenotypic standard deviations, and phenotypic coefficients of variation were estimated for growth, size, condition score, age at puberty, gestation length, and calving difficulty as traits of individual females from 12 breed groups combined, for nine purebreds combined, and for the F_1, F_2, and F_3 generations of three composite populations to which the nine purebreds contributed. Heritabilities and genetic and phenotypic correlations were estimated for growth and size traits, age at puberty, gestation length, and calving difficulty of calves with dams of different ages. Coefficients of variation and genetic standard deviations were similar for composites and contributing purebreds for the traits evaluated. Generally, estimates of heritability were similar for all breed groups combined, contributing purebreds combined, and composites combined. Estimates of heritability for calving difficulty were higher for calves with 2-yr-old dams than for calves with dams ≥ 3 yr old and were sufficiently high (.33 and .26) to be a useful selection criterion for reducing calving difficulty. Estimate of heritability for age at puberty was .31 and for gestation length was .45. The r_g between birth weight and calving difficulty score was higher for calves with 2-yr-old dams (.59) than for calves with dams ≥ 3 yr old (.44). The higher genetic correlation between birth weight and calving difficulty score (.59) in calves with 2-yr-old dams than between birth weight and 368-d weight (.33) suggests opportunity to reduce calving difficulty by reducing birth weight while maintaining 368-d weight. The genetic correlation of gestation length with birth weight was intermediate (.30) and the genetic correlation between gestation length and calving difficulty score was not important (−.07) in calves with dams ≥ 3 yr. Phenotypic correlations were generally lower than genetic correlations among growth and size traits and the phenotypic correlation was intermediate between birth weight and calving difficulty score in calves with 2-yr-old dams (.43).

Key Words: Cattle, Growth, Calving Difficulty, Heritabilities, Genetic Correlations, Phenotypic Correlations

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Introduction

Heritability estimates of, and genetic and phenotypic correlations among, growth traits and between growth traits and calving difficulty have been reported (see Mohiuddin, 1993; Koots et al., 1994a,b). Comparison of composite populations and their contributing purebreds for genetic and phenotypic variation has not been reported. Gregory et al. (1994a,b) suggested composite breeds as an effective procedure to use heterosis simultaneously with using breed differences to achieve and maintain optimum additive genetic composition for specific production and marketing situations. Gregory et al. (1991a,b,c,d; 1992a,b,c) reported results showing that retention of heterosis in composite populations is generally proportional to retention of heterozygosity and that composites offer a more simple procedure than continuous crossbreeding for using heterosis and a more effective procedure for using breed differences to optimize additive genetic composition for specific production and marketing situations. The objective of this study was 1) to estimate genetic and phenotypic variances and heritabilities of, and genetic and phenotypic correlations among, growth, condition score, calving difficulty, age at puberty, and gestation length as traits of individuals from composite and contributing purebred populations of cattle.

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Materials and Methods

Experimental Animals. There were 7,767 females by 662 sires included in this study (Table 1). Composite MARC I is 1/4 Braunvieh, 1/4 Limousin, 1/4 Charolais, 1/8 Hereford, 1/8 Angus; Composite MARC II is 1/4 Gelbvieh, 1/4 Simmental, 1/4 Hereford, 1/4 Angus; and Composite MARC III is 1/4 Red Poll, 1/4 Pinzgauer, 1/4 Hereford, 1/4 Angus. Composite populations included the F_1, F_2, and F_3 generations. In this experiment, the F_1 is defined as the first generation that reflects the final breed composition of a composite population. Experimental animals were born from 1978 to 1991. Composite populations were formed from the same genetic base that was represented in the nine contributing parental breeds. For details on the origin of experimental animal populations see Gregory et al. (1991a,b,c,d; 1992a,b,c).

Mating Procedure. All yearling females were exposed by natural service to yearling males for a mating season of 42 d. After 1987 in Limousin and 1988 in Herefords, males 2 yr old or older were used on yearling females because of late puberty in both sexes of these breeds. Females 2 yr old and older were mated by artificial insemination for 28 d followed by natural service exposure for 28 d, for a mating season of 56 d. Most sires were used in two or more years. From 1978 until 1984, the mating season for yearling heifers was from mid-May until late June and for females 2 yr old and older was from the first of June until late July. Since 1985, the mating season for yearling females was from late May until near mid-July and for females 2 yr old and older was from mid-June until near mid-August. This adjustment of approximately 2 wk in mating and calving season was made to allow greater synchrony of breeding and calving with nutritive and climatic environment. Mating season for yearling females ended immediately before the start of the natural service part of the mating season for females 2 yr old and older in order to use the same single sire mating pastures for both age groups. Open females were retained in all breed groups, unless they were open in two successive years, until 1985. Since 1985, all open females were removed each year from all breed groups. Nonperformance criteria, such as age, color, and extremes in skeletal size, were used to remove excess females to maintain population size for each breed group. Where possible, an attempt was made to maintain a similar age distribution of females in each breed group. Males and females from the F_4 generation of each composite population were removed from the project at an age of 1 yr. This study excluded F_4 females because no data were available after 368 d.

Females in all breed groups were assigned to sires on a stratified random basis within ages in all populations. Half-sib or closer matings were avoided.

The same basic criteria were used to identify males for use in all populations. In all populations the intent was to avoid extremes in regard to weight and condition and muscular and skeletal anatomy. Dystocia was given consideration in identifying males for use in all breed groups. Larger scrotal circumference was favored, particularly in breeds that are late to reach puberty (i.e., Hereford and Limousin [Gregory et al., [1991d]). Polledness and color patterns of red or red with white markings were preferred for males used in all generations of each composite population. An effort was made to maintain a broad pedigree base in all breed groups. The occurrence of genetic defects in some breed groups (i.e., "double muscling" in Gelbvieh, MARC I, and MARC II; "parrot mouth" in Gelbvieh and Braunvieh; malocclusion in Hereford, Angus, and Simmental; hydrocephalus in Red Poll and MARC III; and ataxia in Simmental) resulted in some compromise of pedigree breadth.

Management of Females. Generally, female populations were fed and managed consistent with their requirements. The general plan was to group females in three management units under the day-to-day supervision of an operations coordinator who had operational responsibility for this project. To the extent that a composite population and their contributing parental breeds could be run together in harmony with their feed and management requirements, this was done (i.e., all generations of composite MARC I and Braunvieh, Charolais, and Limousin were managed together [Management Group 1], all generations of composite MARC II and Simmental, Gelbvieh and Pinzgauer were managed together [Management Group 2], and all generations of composite MARC III and Hereford, Angus, and Red Poll were managed together [Management Group 3]). The only deviation from this practice was during the 28-d natural service breeding season when all females were in single-sire mating pastures. The Pinzgauer females were managed with composite MARC II for

Table 1. Number of sires and individuals by breed group - females

Breed group	No. of sires	No. of individuals
Red Poll	43	526
Hereford	43	525
Angus	73	737
Limousin	49	555
Braunvieh	49	497
Pinzgauer	31	319
Gelbvieh	43	418
Simmental	55	528
Charolais	51	556
Composite MARC I - F_1, F_2, F_3	82	992
Composite MARC II - F_1, F_2, F_3	80	1,211
Composite MARC III - F_1, F_2, F_3	63	903
Total	662	7,767

two reasons: to balance numbers in the three management units and because the feed and management requirements of Pinzgauer females are similar to those for Simmental and Gelbvieh. Even though the populations were grouped in the three management units, every effort was made to apply uniform management protocols among the three units. Types of improved pastures (cool- and warm-season grasses), winter feeding programs, and all basic management practices were the same and were provided consistent with requirements. Pastures were contiguous and overlapped for different management groups. All groups received the same feed but the amounts were varied consistent with requirements.

Two-year-old females were fed a mixture of corn silage and alfalfa haylage along with alfalfa and grass hay, starting from 2 to 3 mo before calving and continuing until pastures were adequate to meet their requirements, which was usually in mid- to late April. All older females were fed mixtures of alfalfa and grass hay to meet nutritive requirements, usually from November until mid- to late April. After 1986, economic considerations favored feeding these females limited quantities of corn silage and alfalfa haylage during the period of winter feeding.

Feeding Young Females. Calves were weaned at an average age of approximately 180 d. Mean birth date was April 7 and calves were weaned the 1st wk of October in most years. Following an adjustment feeding period (28 d), females were fed diets composed of corn silage, alfalfa haylage, and protein-mineral-vitamin supplement in varying proportions and lengths of time, depending on weather conditions and weight gains of heifers: 1) Period 1, 2.34 Mcal of ME/kg of DM, 11.62% CP; 2) Period 2, 2.24 Mcal ME/kg DM, 12.34% CP; and 3) Period 3, 2.18 Mcal ME/kg DM, 11.70% CP until placed on improved cool-season grass pasture from mid- to late April depending on adequacy to meet nutritive requirements. The three time periods were of approximately equal length.

Data Collection. Calves were weighed at birth, mid breeding season (end of AI breeding period), at weaning, and 28, 84, 140, and 168 d postweaning. Hip height was measured 168 d postweaning. Observations for estrus started March 1 and continued to the start of mating period. Heifers were weighed at the start of breeding season (410 d), end of breeding season (452 d), and when palpated for pregnancy diagnosis (522 d). Heifers not observed in estrus and not conceiving were excluded from the analysis for age at puberty.

Calving difficulty was subjectively evaluated using descriptive scores (i.e., 1 = no difficulty, 2 = little difficulty by hand, 3 = little difficulty with calf jack, 4 = slight difficulty with a calf jack, 5 = moderate difficulty with calf jack, 6 = major difficulty with calf jack, 7 = Caesarean birth, and 8 = abnormal presentation). Percentage calving difficulty was analyzed (scores 1 and 2 = 0; scores 3, 4, 5, 6, and 7 = 1). Calves with abnormal presentation were excluded from the analyses of calving difficulty. Twin calves and calves raised by foster dams were excluded from all analyses. Weights at 200 and 368 d were estimated using birth weight and preweaning and postweaning average daily gain, respectfully.

Estimates of heritability of weights, heights, and condition scores at 2, 3, 4, and 5 yr are based on means of observations made approximately 2 mo before start of calving, immediately before start of breeding, and when pregnancy status was determined approximately 1 mo after weaning. Estimates of heritability of weight at 1 yr are based on the mean of weights taken immediately before the start of breeding (410 d), end of breeding (452 d), and at pregnancy diagnosis (522 d). Estimates of h^2 of hip height and condition score at 1 yr are based on mean of observations at 368 and 522 d. Height and condition score were not recorded at 410 and 452 d.

Cows were weighed, measured for hip height, and scored for condition three times each year (i.e., in February approximately 2 mo before calving, in June before the start of the breeding season, and in October when they were palpated for pregnancy). Data on cows that did not raise a calf were excluded from the analyses.

Analysis of Data. Data were analyzed by least squares mixed model procedures (Harvey, 1985). Three primary analyses were conducted. The fixed effects included in the model were breed group (nine parental breeds in the model for purebreds, three composite populations in the model for composites, and nine parental breeds plus three composites in the model for combined analyses), year of birth, age of dam (2, 3, 4, and ≥ 5) of individual, and the regressions of each trait on date of birth and on date of birth within breed group. The regressions on date of birth and on date of birth within breed group were both significant for many of the traits included in the analyses. Interactions among main effects were not important ($P > .05$). Sire of individuals within breed group was included in the model as a random effect for each analysis. Separate analyses were run on calves with 1) dams of all ages, 2) calves with 2-yr-old dams, and 3) on calves with dams ≥ 3 yr old. The objective of the separate analyses for calves with 2-yr-old dams was to obtain estimates of heritability (h^2) and genetic correlations (r_g) involving calves with dams of this age. The separate analyses for calves with dams ≥ 3 yr were performed because data on gestation length were not available on calves with 2-yr-old dams because there was no AI in yearling heifers. Pooled estimates of variance components among sires (σ_s^2) and residual (σ_e^2) were used to estimate genetic (σ_g) and phenotypic (σ_p) standard deviations. Genetic standard deviations were estimated by $\sqrt{4 \times \sigma_s^2}$. Phenotypic standard deviations were estimated by $\sqrt{\sigma_s^2 + \sigma_e^2}$. Heritability ($h^2$) was estimated by $4\,\sigma_s^2/(\sigma_s^2 + \sigma_e^2)$. Coefficients of variation (CV) were computed

CV = $\sigma p/\bar{x}$. Genetic and phenotypic correlations were calculated by $COV_{si\ sj}/(\sigma_{si} \times \sigma_{sj})$ and $COV\ P_i\ P_j/(\sigma P_i \times \sigma P_j)$, respectively, where s_i and s_j refer to genetic value of traits i and j and where P_i and P_j refer to phenotypic value of traits i and j.

In each analysis the component breed groups are assumed to have a common variance. The estimates of genetic (co)variances reflect average values for breed groups included in each of the three primary analyses.

The sire model provided by the LSMLMW program (Harvey, 1985) was chosen over alternative models and programs (e.g., MTDFREML, Boldman et al., 1993) because it was important to estimate covariances among a large number of traits in the analyses. Computing efficiency greatly favored the use of the sire model over alternative models. Also, the advantages of using MTDFREML are believed to be relatively small because the parental purebred and composite populations were unselected and matings provided for a low rate of inbreeding.

Results and Discussion

Information on number of sires and individuals in each population included in this study is provided by Table 1.

Results presented in Tables 2, 3, and 4 reflect analyses of traits of individual females.

Genetic and Phenotypic Standard Deviations and Phenotypic Coefficients of Variation. Estimates of genetic (σ_g) and phenotypic (σ_p) standard deviations and phenotypic coefficients of variation (CV) are presented in Table 2 for 1) all breed groups combined, 2) purebreds combined, and 3) composites combined. Differences in σ_g and CV were generally small and not important among all breed groups combined, purebreds combined, and composites combined. There was not a tendency for higher σ_g and CV for composites than for contributing purebreds. For traits associated with size, σ_p tended to be larger for composites than for contributing purebreds because phenotypic variation tends to be proportional to the

Table 2. Least squares means, genetic and phenotypic standard deviations, and phenotypic coefficient of variation for all breed groups, purebreds, and composites - females

	All breed groups				Purebreds				Composites			
Trait	σ_g	σ_p	$\bar{x}$	CV	σ_g	σ_p	$\bar{x}$	CV	σ_g	σ_p	$\bar{x}$	CV
Birth wt, kg	3.0	4.6	39.7	.12	3.1	4.4	39.5	.11	2.9	4.9	40.5	.12
Preweaning ADG, kg	.055	.095	.900	.10	.055	.093	.891	.10	.046	.096	.932	.10
200-d wt, kg	11.6	20.4	220	.09	12.3	20.0	218	.09	9.6	20.7	227	.09
Postweaning ADG, kg	.062	.103	.700	.15	.062	.104	.689	.15	.064	.102	.736	.14
368-d wt, kg	18.1	29.4	337	.09	19.0	28.8	334	.09	16.7	30.2	351	.09
410-d wt, kg	16.6	29.5	337	.09	18.1	28.7	334	.08	15.1	30.6	348	.09
452-d wt, kg	19.3	30.0	376	.08	21.6	29.1	373	.08	16.2	31.1	386	.08
522-d wt, kg	20.2	30.3	393	.08	22.5	29.3	390	.08	17.2	31.6	404	.08
Wt, 1 yr, kg	19.12	28.51	370	.08	21.20	27.57	367	.08	16.86	29.68	381	.08
Wt, 2 yr, kg	27.32	35.30	468	.08	27.89	33.75	465	.07	26.97	36.98	482	.08
Wt, 3 yr, kg	29.63	42.55	519	.08	31.39	41.24	516	.08	28.57	43.76	531	.08
Wt, 4 yr, kg	30.19	44.67	570	.08	25.12	43.04	568	.08	35.74	46.04	577	.08
Wt, 5 yr, kg	31.58	45.49	592	.08	33.88	41.44	592	.07	32.29	48.06	596	.08
368-d ht, cm	2.2	3.4	120	.03	2.1	3.2	120	.03	2.3	3.6	120	.03
Ht, 1 yr, cm	2.30	3.20	124	.03	2.26	3.07	124	.02	2.36	3.35	124	.03
Ht, 2 yr, cm	2.30	3.05	131	.02	2.32	2.90	131	.02	2.31	3.24	131	.02
Ht, 3 yr, cm	2.23	3.25	133	.02	2.42	3.12	133	.02	2.02	3.39	133	.02
Ht, 4 yr, cm	2.14	3.21	134	.02	2.24	3.04	134	.02	2.02	3.37	134	.02
Ht, 5 yr, cm	1.72	3.20	135	.02	1.71	2.96	135	.02	1.99	3.36	134	.02
368-d cond. score[a]	.6	.9	5.10	—	.6	.9	4.92	—	.5	.9	5.65	—
Cond. score, 1 yr[a]	.41	.65	4.99	—	.45	.66	4.84	—	.35	.64	5.47	—
Cond. score, 2 yr[a]	.40	.61	5.31	—	.46	.60	5.16	—	.34	.61	5.76	—
Cond. score, 3 yr[a]	.43	.66	5.09	—	.41	.66	4.96	—	.40	.65	5.51	—
Cond. score, 4 yr[a]	.46	.64	5.54	—	.48	.65	5.42	—	.36	.62	5.93	—
Cond. score, 5 yr[a]	.39	.62	5.55	—	.41	.62	5.44	—	.21	.63	5.90	—
C.D. score, 2 yr[b]	.62	1.08	1.92	—	.69	1.08	1.84	—	.52	1.08	1.72	—
C.D. %, 2 yr[b]	24.0	46.65	43.0	—	23.61	45.99	40.40	—	26.02	48.27	36.88	—
C.D. score ≥ 3 yr[b]	.14	.30	1.05	—	.14	.32	1.05	—	.12	.28	1.03	—
C.D. %, ≥ 3 yr[b]	6.84	18.75	4.31	—	.10	20.42	4.38	—	3.27	15.95	2.67	—
C.D. score, all ages	.33	.59	1.22	—	.38	.62	1.23	—	.24	.55	1.21	—
C.D. %, all ages	11.67	28.26	12.56	—	12.70	29.40	12.79	—	9.80	26.40	12.20	—
Gestation length, d	2.51	3.74	287	.01	2.19	3.75	286	.01	2.83	3.70	287	.01
Puberty age, d	15.15	27.10	371	.07	15.69	28.39	374	.08	13.63	25.05	365	.07

[a]Scale 1 to 9; 9 = very fat, 1 = emaciated.
[b]C.D. = Calving difficulty; scale 1 to 7.

mean. The low CV for height at all ages is noted for all groupings of populations. This reflects small σ_p relative to the means. There was a high degree of similarity among the three groupings in CV for traits with a normal distribution (e.g., size). Because of the arbitrary nature of the scale for scores, CV are not presented for traits for which differences were evaluated by subjective score.

Heritabilities. Estimates of heritability (h^2) are presented in Table 3 for 1) all breed groups combined, 2) purebreds combined, and 3) composites combined. Generally, there was close agreement in h^2 among the three groupings. There was not a tendency for higher h^2 in composites than in contributing purebreds. Because of similarity of h^2 among breed groupings and the generally lower standard errors because of greater numbers, only h^2 for all breed groups combined are discussed.

Because additive genetic variation depends on the number of polymorphic loci that affect a trait and the frequencies and effects of polymorphic alleles, composite populations formed with contributions by four or five breeds potentially have more polymorphic loci and more alleles at intermediate frequencies. However, additive genetic variation of composites relative to contributing purebreds was not consistent with this expectation in this study.

The h^2 of weights were remarkably similar at all ages. The h^2 of height and condition score were similar at all ages except 5 yr, at which point both were lower. Because of a decrease in numbers with increasing age, standard errors tend to increase with age (Table 3). Higher h^2 were expected for weights, heights, and condition scores at 1, 2, 3, 4, and 5 yr than at 368 d and earlier because h^2 of weight, height, and condition score are based on means of three observations made in different seasons at 1 through 5 yr. The h^2 for weights, heights, and condition scores through 368 d were similar to those reported for males from the same

Table 3. Heritabilities (h^2) and standard errors (SE) for all breed groups, purebreds, and composites - females

	All breed groups (n = 7,767)		Purebreds (n = 4,661)		Composites (n = 3,106)	
	h^2	SE	h^2	SE	h^2	SE
Birth wt, kg	.42	.04	.48	.05	.36	.06
Preweaning ADG, kg	.33	.03	.35	.04	.24	.05
200-d wt, kg	.32	.03	.38	.05	.21	.04
Postweaning ADG, kg	.37	.04	.36	.04	.39	.06
368-d wt, kg	.38	.04	.43	.05	.31	.05
410-d wt, kg	.32	.03	.40	.05	.24	.05
452-d wt, kg	.42	.04	.55	.05	.27	.05
522-d wt, kg	.45	.04	.59	.06	.30	.05
Wt, 1 yr, kg[a]	.45	.04	.59	.06	.32	.06
Wt, 2 yr, kg[a]	.52	.06	.58	.07	.47	.08
Wt, 3 yr, kg[a]	.43	.06	.50	.09	.38	.09
Wt, 4 yr, kg[a]	.41	.08	.31	.10	.52	.12
Wt, 5 yr, kg[a]	.43	.10	.57	.15	.41	.14
368-d ht, cm	.43	.04	.43	.05	.43	.06
Ht, 1 yr, cm[a]	.52	.04	.54	.06	.49	.07
Ht, 2 yr, cm[a]	.50	.05	.55	.07	.45	.08
Ht, 3 yr, cm[a]	.42	.06	.52	.09	.32	.09
Ht, 4 yr, cm[a]	.40	.08	.48	.11	.33	.11
Ht, 5 yr, cm[a]	.27	.10	.31	.15	.32	.13
368-d cond. score[b]	.40	.04	.45	.05	.31	.05
Cond. score, 1 yr[ab]	.40	.04	.46	.06	.29	.05
Cond. score, 2 yr[ab]	.40	.05	.50	.07	.28	.07
Cond. score, 3 yr [ab]	.38	.06	.36	.08	.36	.09
Cond. score, 4 yr[ab]	.47	.08	.49	.11	.31	.10
Cond. score, 5 yr[ab]	.29	.10	.40	.15	.11	.11
C.D. score, 2 yr[c]	.33	.09	.42	.11	.24	.14
C.D. %, 2 yr[c]	.26	.09	.26	.11	.29	.14
C.D. score, ≥ 3 yr[cd]	.20	.05	.20	.07	.18	.08
C.D. %, ≥ 3 yr[cd]	.13	.05	.16	.07	.04	.07
C.D. score, all ages[c]	.31	.03	.37	.05	.18	.04
C.D. %, all ages[c]	.17	.03	.18	.04	.14	.04
Gestation length, d[d]	.45	.06	.34	.08	.58	.10
Puberty, d	.31	.04	.30	.05	.30	.06

[a]Based on a mean of three observations.
[b]Scale 1 to 9; 9 = very fat, 1 = emaciated.
[c]C.D. = calving difficulty; scale 1 to 7.
[d]Calves conceived by artificial insemination.

population (Gregory et al., 1995).

The h^2 for calving difficulty score for calves with 2-yr-old dams, for calves with dams ≥ 3 yr, and for calves with dams of all ages generally were higher than for percentage calving difficulty. This is expected because percentage calving difficulty is expressed as a binary trait (e.g., 0 or 1), whereas calving difficulty score is classified into seven categories.

The h^2 of calving difficulty score and percentage calving difficulty were higher for calves with 2-yr-old dams than for calves with dams ≥ 3 yr old. This is likely associated with the higher frequency of calving difficulty of calves with 2-yr-old dams (Gregory et al., 1991c). However, the h^2 of calving difficulty of female calves was similar to that of male calves (Gregory et al., 1995), and male calves experience a higher frequency of calving difficulty than female calves (Gregory et al., 1991c).

The h^2 for gestation length for female calves with dams ≥ 3 yr was the same as for male calves (.45 vs. .46) in this experiment (Gregory et al., 1995). The h^2 for age at puberty (.31) is slightly lower than the estimate of .40 reported by Laster et al. (1979).

The estimates of h^2 for weight and height to yearling age in our study tend to be higher for weights but lower for height than the weighted mean h^2 based on literature reports of .31 for birth weight, .29 for preweaning gain, .24 for weaning weight, .31 for postweaning gain, .33 for yearling weight, and .61 for yearling height, as traits of the individual (Koots et al., 1994a).

For calving ease (direct) expressed as percentage unassisted, Koots et al. (1994a) reported a weighted mean h^2 estimate of .13 for cows and .10 for heifers. Our estimates of h^2 are higher for calving difficulty score of .33 for calves with 2-yr-old dams, .20 for calves with dams ≥ 3-yr-old, and .31 for calves with dams of all ages as a trait of the calf.

Genetic Correlations. Estimates of genetic correlations (r_g) and their standard errors for all breed groups combined are presented below the diagonal among selected traits in Table 4. Separate analyses were run for different age classes of individuals. Data recorded through 522 d were included in all analyses, and data recorded at each of 1, 2, 3, ≥ 3, 4, and 5 yr were added and were run as separate analyses. A reason for this approach was to use all of the data available in each age class. For example, gestation length was available only on calves conceived by artificial insemination for females ≥ 3 yr. Furthermore, many of the females had been removed from their population based on nonperformance criteria at an age of 5 yr. Differences in magnitude of standard errors for h^2 in Table 3 reflect differences in the number of observations for different traits. The r_g were not estimated among all the 33 traits shown in Tables 2 and 3. Only the r_g among selected weights, heights, condition scores, calving difficulty scores, gestation length, and age at puberty are presented in

Table 4. Genetic[a] and phenotypic[b] correlations among growth and size traits and some reproductive traits in beef females

Trait	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
1. Birth wt		.40	.42	.42	.40	.44	.46	.42	.02	.03	−.03	.43	.12	.29	.05
2. 200-d wt, kg	.34 ± .06		.82	.61	.50	.56	.50	.39	.19	.20	.08	.10	.04	.06	−.12
3. 368-d wt, kg	.33 ± .06	.84 ± .02		.76	.64	.63	.58	.49	.32	.27	.13	.14	.05	.07	−.11
4. Wt, 2 yr, kg[c]	.36 ± .07	.74 ± .05	.85 ± .03			.58	.69		.11	.47		.09			.00
5. Wt, 5 yr[c]	.08 ± .21	.66 ± .12	.83 ± .08			.48		.70	.10		.41				.01
6. 368-d ht, cm	.35 ± .06	.66 ± .04	.70 ± .04	.68 ± .06	.51 ± .15		.77	.71	−.05	−.04	−.12	.18	.03	.08	−.06
7. Ht, 2 yr, cm[c]	.49 ± .07	.63 ± .06	.67 ± .05	.74 ± .04		.92 ± .02			−.11	.02		.10			.02
8. Ht, 5 yr, cm[c]	.25 ± .24	.44 ± .18	.48 ± .46		.47 ± .16	.88 ± .10			−.17		−.02				.03
9. 368-d cond. score[d]	−.02 ± .07	.14 ± .07	.25 ± .07	.15 ± .08	.24 ± .16	−.15 ± .07	−.03 ± .09	−.23 ± .21		.26	.21	−.02	−.03	.04	−.09
10. Cond. score, 2 yr[cd]	.03 ± .09	.32 ± .09	.36 ± .08	.48 ± .07		.01 ± .10	.10 ± .09		.30 ± .09			.00			−.02
11. Cond. score, 5 yr[cd]	−.20 ± .25	−.02 ± .21	.34 ± .20		.56 ± .16	−.14 ± .24		−.14 ± .26	.36 ± .18						−.06
12. C.D. score, 2 yr[e]	.59 ± .14	.06 ± .15	.09 ± .16	.09 ± .09		.20 ± .16	.00 ± .09		.09 ± .13	−.14 ± .10					
13. C.D. score, ≥ 3 yr[e]	.44 ± .14	.36 ± .17	.24 ± .16			.12 ± .15			.09 ± .18					.05	
14. Gestation length, d	.30 ± .10	−.23 ± .12	−.14 ± .12			−.14 ± .11			.06 ± .13				−.07 ± .14		
15. Puberty age, d	.03 ± .08	−.14 ± .09	−.05 ± .08	.11 ± .12	−.05 ± .10	−.11 ± .08	.17 ± .12	.02 ± .11	−.02 ± .08	−.09 ± .14	−.17 ± .11				

[a]Genetic correlations and their standard errors are below diagonal.
[b]Phenotypic correlations are above diagonal.
[c]Based on a mean of three observations.
[d]Scale 1 to 9; 9 = very fat, 1 = emaciated.
[e]C.D. = calving difficulty score; scale 1 to 7.

Table 4. These are believed to be the traits of greatest interest in each category. For example, percentage of calving difficulty is not included because calving difficulty score is a more descriptive evaluation of differences in the trait than is percentage of calving difficulty.

The r_g between birth weight and subsequent weights were similar for all ages to 2 yr but not at 5 yr. The large standard error reflects the relatively small number of observations at 5 yr. The r_g between weight and height generally were high at each age. The r_g for weight and height with condition score were variable at each age but they tended to be relatively low. The r_g for 200 and 368-d weight with subsequent weights were much higher than birth weight with subsequent weights. The r_g between height at 368 d and height at subsequent ages were only slightly higher than r_g between weight at 368 d and weight at subsequent ages. The r_g between condition score at 368 d and subsequent ages were relatively low (e.g., .30 and .36). Calving difficulty score of calves with 2-yr-old dams was not correlated with height at 368 d or at 2 yr (e.g., .20 and .00, respectively). The r_g between calving difficulty score of calves with 2-yr-old dams and weight at 2 yr was low (.09) and not important.

The r_g between birth weight with calving difficulty score at 2 yr was higher (.59) than with calving difficulty score at ≥ 3 yr (.44). The higher r_g between birth weight and calving difficulty score at 2 yr (.59) than between birth weight and 368-d weight (.33) suggests some opportunity to reduce calving difficulty score by reducing birth weight while maintaining 368-d weight. A similar conclusion was drawn by Dickerson et al. (1974) in which a selection index of I = [(368-d weight) − (3.2 × birth weight)] was suggested. Mendoza and Slanger (1985) reported results suggesting opportunity to reduce birth weight while maintaining yearling weight. These estimates of r_g for females are similar to the r_g for males from the same population, with the exception of r_g between gestation length and calving difficulty score of calves from females ≥ 3 yr, which was considerably higher with males (.57 vs .07) (Gregory et al., 1995).

Our estimates of r_g of calving difficulty score as a trait of the individual for calves with 2-yr-old dams and for calves with dams ≥ 3 yr old were, respectively, .59 and .44; .06 and .36; and .09 and .24 with birth, weaning, and yearling weight. These values compare with the weighted mean values reported by Koots et al. (1994b) expressed as calving ease as a trait of the individual of −.74 with birth weight, −.21 with weaning weight, and −.29 with yearling weight.

Phenotypic Correlations. Estimates of phenotypic correlations (r_p) are presented among selected traits above the diagonal in Table 4. The r_p followed the pattern of the r_g but generally were lower. The r_p between weights at different ages and between heights at different ages and between weights and heights at the same age were relatively high. The r_p of calving difficulty score at the ages presented, gestation length, and age at puberty with weight, height, and condition score at 368 d generally were low and not important.

Implications

Composite breeds of cattle are similar to their contributing purebreds in phenotypic and genetic variation for growth and size traits. Thus, response to selection should be similar. Selection for reduced calving difficulty score should be moderately effective based on a heritability of .33 for calves with 2-yr-old dams. Further, because of the higher genetic correlation between birth weight and calving difficulty score (.59) in calves with 2-yr-old dams than between birth weight and 368-d weight (.33) there is opportunity to reduce calving difficulty by reducing birth weight while maintaining 368-d weight.

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